Material Transport with Linear Induction

Behrens, B.-A.; Krimm, R.; Commichau, O.

Abstract

Currently used material feeding systems are limited in their dynamics. An innovative material feeding system, which can move conductive material contactless and highly dynamic with any geometry is proposed in this paper. The concept is based on the linear induction motor, while the workpiece itself functions as the runner of the motor. Field forming elements that guide the magnetic field towards the workpiece are proposed. Electromagnetic FEA simulations were carried out on the system. The functionality was proven by means of a demonstrator being able to move metallic tubes towards given positions.

1 INTRODUCTION

With the steady improvement of production technologies, new concepts for material feeding systems are required. In a fully automated production line, a highly dynamic material transport between each processing step is mandatory for having a maximized output rate. Especially while moving material with a sensitive surface or coating, the feeding system needs to handle the workpiece gently. The movement is typically achieved by material feeding systems. Currently used systems move the material by grippers or by pressing the workpiece between two rotating cylinders (Fig. 1)[1, 2]. The downside of this method is that the frictional force can cause damage on the surface of the material. Also, the effect of stick-slip can appear, which causes inaccuracies and substandard output.

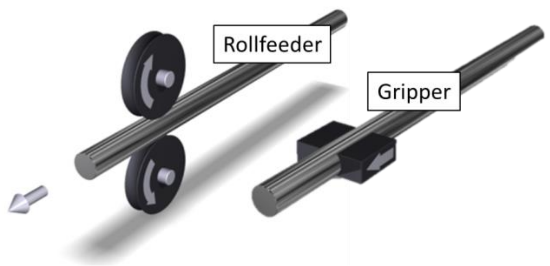

Fig. 1 Conventional feeding systems

In this paper, a new concept for material feeding systems for electrically conductive material is presented. The concept of the linear induction motor is used to move conductive material by means of electromagnetic force. The electromagnetic field originates from two inductors (primary parts) that are connected to the 3-phase alternating current grid. Field forming elements guide the magnetic field towards the workpiece in order to minimize the airgap between the workpiece and the primary parts.

2 ELECTROMAGNETIC FEEDING

Applications for linear drives have been presented in [3, 4]. A method of moving sheet metal based on the principle of the linear induction motor is described in [5]. A double sided arrangement is provided where two identical inductors are symmetrically fixed positioned above and beneath the sheet metal to suppress unilateral forces. The sheet metal itself functions as the runner of the motor. The device applies feeding forces higher than 1 kN on the sheet metal.

In linear induction motors, an electromagnetic wave is produced by the 3-phase alternating current grid. The electromagnetic wave induces eddy-currents in the runner. A mutual reaction between the eddy-currents and the magnetic field results in a Lorentz-Force in feeding direction.

In order to achieve high energy efficiency, a small airgap between the inductor and the sheet metal is necessary. For this reason, the concept cannot simply be adapted to other workpieces than sheet metal. The inductor is typically flat sided, therefore a large airgap appears if material with different geometries is being moved, as illustrated in Fig. 2.

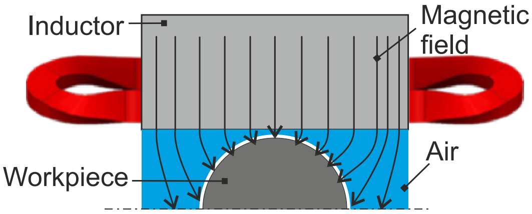

Fig. 2 Airgap between the inductor and the workpiece

The magnetic field, represented by the black lines, does not focus towards the workpiece, leaving fractions of the magnetization unused. Air has low permeability towards magnetic fields and with the magnetic field having to overcome a large airgap, the magnetic circuit would have high magnetic resistance. This leads to suboptimal energy efficiency.

The Institute of Forming Technologies and Machines performs research on a new concept for electromagnetic material feeding systems. In this concept, magnetic field is guided towards the workpiece by field forming elements with high magnetic permeability. Fieldforming elements were used in [6] to focus eddy-currents in an electromagnetic forming operation.

Fig. 3 shows the setup. The field formers are placed on the inductor as an extension of the inductor teeth.

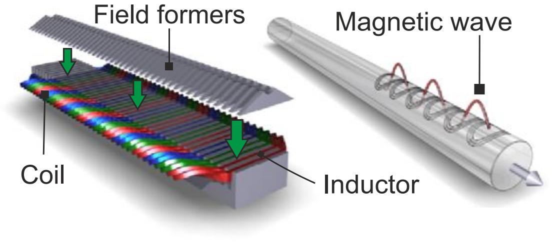

Fig. 3 Concept for moving conductive material with a non-flat surface

The field formers are packaged along the length of the inductor, spacers between the single pieces ensure the correct distance between the elements. The shape of the field formers matches with the inductor on one side and with the workpiece on the other side, leaving a minimized airgap in between (see Fig. 4).

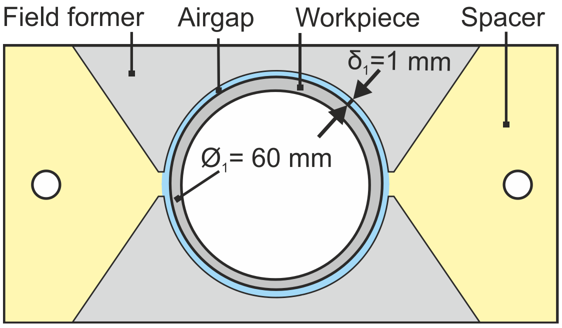

Fig. 4 Concept for the field formers

3 FEA SIMULATIONS

The system and the internal physical processes are highly complex. In order to perform studies on the electromagnetic system, a finite element model was built. The software Ansys was used to build a parametric model, using the Ansys internal scripting language Ansys APDL (Ansys Programming Design Language). The script can run in loops while varying single parameters which highlights the influence of single parameters on the system. The system is reduced to ¼ of the total size while using boundary conditions, in order reduce the demand of computational resources (see Fig. 5).

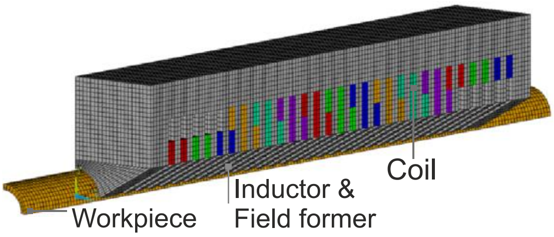

Fig. 5 FEA-Model of the feeding device

The coloured sections in the inductor represent the three phases of the alternating current grid. Current-densities are applied on the conductors. Electromagnetic simulations were performed to investigate the magnetic induction, the eddy-currents in the workpiece and to prove the functionality of the concept. The simulations were carried out in a loop under variation of single parameters in order to find an optimized set of design parameters for an energy efficient system that provides high feeding forces.

The resulting force depends on the frequency of the excitation. Characteristically, the force increases when the frequency increases. However, this is only true until the force reaches a maximum at the so called slip frequency. At higher frequencies, the force decreases. The slip frequency depends on the conductivity of the workpiece. Investigations were carried out for a stator with 10 poles along the length of the inductor, while the conductors are excited with a current of 30 A. The field forming elements are designed to match circular beams with a diameter of 60 mm. The resulting forces for a steel, a copper and an aluminum beam are shown in Fig. 6. Steel is a magnetic material leading to a better magnetic induction in the circuit and higher feeding forces respectively than with aluminum or copper.

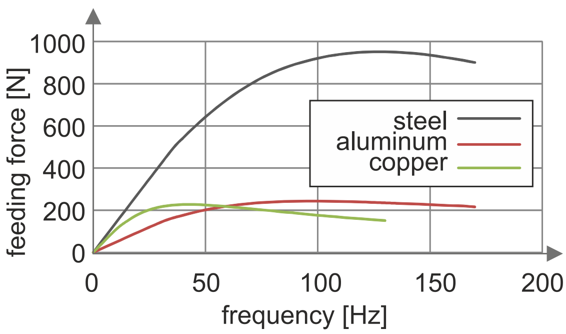

Fig. 6 Slip frequencies for different materials

The magnetic induction is shown in Fig. 7. Magnetic circuits build up along the length of the inductor and field formers. The magnetic circuits are caused by the excitation of the conductors. The maximum induction is at 2.4 T which is in the area of saturation. For this reason, a nonlinear magnetization curve for the inductor material was implemented in the model to ensure high model accuracy.

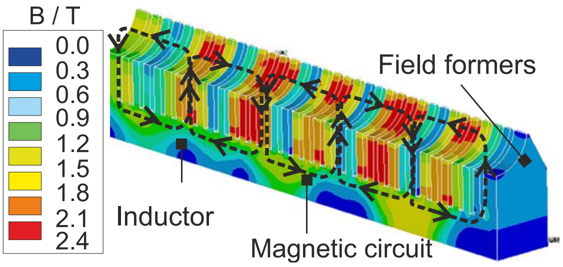

Fig. 7 Magnetic field along the inductor and field formers

The magnetic field circles through the inductor and the workpiece, causing induction in the workpiece. In Fig. 8 the cross sectional view of a steel tube with the magnetic induction inside is shown. The depth of the field depends on the frequency of the excitation. With increasing frequency, the induction depth in the workpiece decreases. The studies have shown, that the wall thickness needs to be more than 3 mm for a maximum usage of the magnetization at 120 Hz, which is the slip frequency.

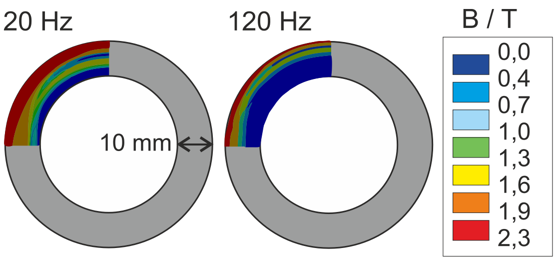

Fig. 8 Induction depth at different Frequencies

In a further study, the FEA model was modified to investigate other geometries than a circular tube. The feeding forces for a square profile and a hexagon profile have been calculated using field formers as shown in Fig. 9. The results show similar behavior of the system, leaving no doubt, that the package of field formers is a great extension to the simple inductor. This gives the opportunity to move any kind of geometry simply by adjusting the geometry of the field formers.

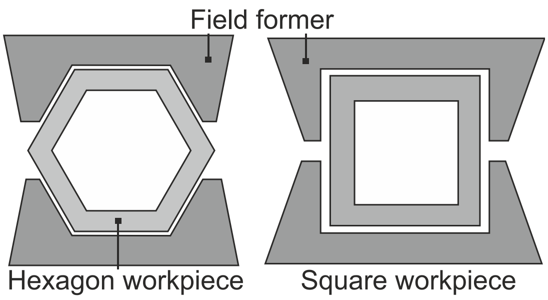

Fig. 9 Modified field former geometry

4 DEMONSTRATOR DESIGN

Using the FEA model, a set of design parameters for a demonstrator to build a highly efficient feeding device to move circular rods with 60 mm diameter, was found. The demonstrators main purpose is to prove the results of the FEA studies. The motor is designed as a double-sided linear motor, consisting of one inductor above and another inductor beneath the workpiece.

Harmonic waves can appear in linear induction motors, which limit the magnetic induction [7]. The coils were arranged in specific order to minimize this effect and ensure the best possible magnetization as described in [8]. The field forming elements are packaged and located between the inductors. The workpiece is held in position by rolls that are located in front of and behind the inductor *(see Fig. 10).* In order to ensure that the inductors do not overheat, passive cooling systems are installed on the backside of the inductors. The feeding distance for the controlling system is measured by an encoder, which is positioned at the front of the feeding system. The encoder is connected to a shaft with a mounted PU-cylinder, which is gently pressed against the workpiece. When the workpiece moves, a rotation on the cylinder results which is being recorded by the encoder. This information is used by the controller to determine the actual feeding distance.

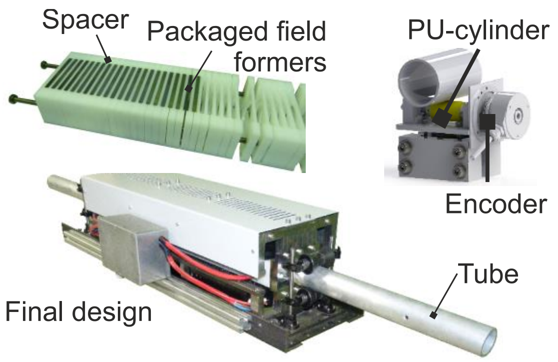

Fig. 10 Demonstrator for the validation

5 EXPERIMENTAL SETUP AND VALIDATION

5.1 MAXIMUM FORCE

The achievable feeding force was measured by a force sensor, which was rigidly connected to the circular tube. The experiments were carried out with an aluminum tube with a diameter of 60 mm and variation of the frequency. Fig. 11 shows the results. The experimental results and the simulation align quite well in the span between 0 and 75 Hz. The measured forces drop instantly at frequencies higher than 75 Hz. The impedance of the system, which is proportional to the frequency of the current, causes this force drop. The system cannot run at the nominal current of 29 A at frequencies higher than 75 Hz, which is the reason for the decreasing feeding force. Besides this technical limit the correlation proves, that the FEA model delivers valid results.

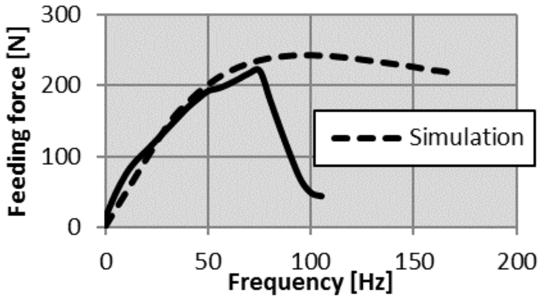

Fig. 11 Results of the force measurements

5.2 POSITIONING AND DYNAMIC EXPERIMENTS

A built in linear positioning module in the frequency converter is used as the controller for the dynamic experiments. The information on the position delivered from the encoder is processed by the controller. The absolute positioning accuracy, the repeatability of positioning and maximum achievable stroke rates were determined using an optical measuring system. Reference markers are applied on the workpiece and the frame. They are located by the optical measuring system which determines the relative movement between those markers. The movement of the rod is measured with an accuracy of ±9 µm. During the experiments the rod was moved in 20 mm steps. The misplacement after each step is shown in Fig. 12. The measured accuracy is between -62 and +58 µm (0.3%).

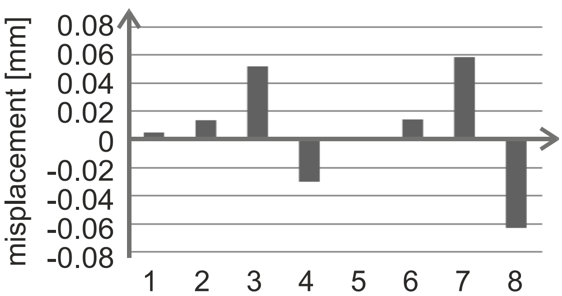

Fig. 12 Accuracy of the device

The achievable stroke rate was determined by means of an experimental approach. The stroke rate depends on the feeding distance, the feeding force, as well as the weight of the workpiece. The weight could change with every processing step during the machining process. The workpiece is moved in standard velocity profile, which includes a section of acceleration, constant speed and deceleration. For short feeding distances, the maximum speed will never be reached, which eliminates the constant speed section.

In this experiment, the tube was moved with a feeding distance of 150 mm. Based on the results, the stroke rate vs weight of the workpiece was calculated. The results of the calculation are shown in Fig. 13. The solid line represents the calculated stroke rates with the previously described 10-pole demonstrator. Stroke rates of 400/min could be reached, depending on the weight of the workpiece. The dashed lines show the possible feeding rates with an increased number of poles.

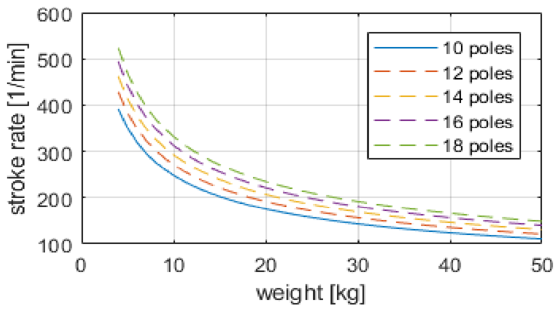

Fig. 13 Achievable stroke rates

6 SUMMARY

In this paper, an innovative feeding system, which is able to move electrically conductive material contactless by means of electromagnetic force is described. The con-cept is based on the linear induction motor, while using the workpiece as the runner of the motor. Field forming elements were investigated to guide the magnetic field between the inductor and the workpiece for minimal losses. An FEA model was built and electromagnetic simulations were carried out to optimize the design of the device in terms of energy efficiency. For validation, a feeding system was constructed and built which moves metallic tubes with a diameter of 60 mm. The results show a good correlation with the simulations.

7 ACKNOWLEDGEMENT

The IGF-project 18863 N/1 of the German Machine Tools' Association (VDW) is supported via the German Federation of Industrial Research Associations (AiF) within the framework of the Industrial Collective Research (IGF) program by the Federal Ministry of Economics and Technology on the basis of a decision by the German Bundestag.

The Authors would like to thank the VDW and the members of the industrial consortium for supporting the research activities.

8 REFERENCES

[1] Hauri, H.: Zuführeinrichtungen für Bänder und Streifen zu Stanzpressen - Teil 2, TECHN.RDSCH. * Band 66 (1974) Heft 18

[2] Wanzke M.: Entwicklung eines lärmarmen, anschlaglosen Zangenvorschubgerätes mit Eigenantrieb, auch für vorhandene Pressen und Stanzen. Bremerhaven, Wirtschaftsverl. N.W., 1986,

[3] Behrens B.-A.; Krimm R.; Reich D.; Teichrib, S.: Linear drives in metal forming machines and peripherals-recent developments, Journal of Manufacturing Processes, pp. 192-198, 2016

[4] Behrens, B.-A.; Bouguecha, A.; Krimm, R.; Teichrib, A.; Nitschke, T.: Energy-efficient Drive Concepts in Metal-forming Production, Procedia CIRP 50, pp. 707-712, 2016

[5] Teichrib, S.; Krimm, R.; Behrens B.-A: Electromagnetic Sheet Metal Feeder, Key Engineering Materials, Vols. 611-612, S. 939-946, 2014

[6] Golowin S.; Kamal M.; Shang J.; Portier J.; Din A.; Daehn, G.S.; Bradley3, J.R.; Newman, K.E.; Hatkevich, S.: Application of a uniform pressure actuator for electromagnetic processing of sheet metal, Journal of Materials Engineering and Performance, 16 (4), pp. 455-460, 2007

[7] Bazghaleh, A.Z.; Naghashan, M.R.; Mahmoudimanesh, H.; Meshkatoddini, M.R.: Effective design parameters on the end effect in single-sided linear induction motors, World Academy of Science, Engineering and Technology, 64, pp. 95-100, 2016

[8] Grop, H.: Investigation of AC Electrical Machine Stators with Fractional Conductor Windings, KTH Stockholm, Sweden, 2010

Author: Commichau, Oliver

University: Leibniz Universität Hannover

Department: Institute of Forming Tech-nologies and Machines

E-Mail: commichau@ifum.uni-hannover.de